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Abstract:

Over the past year, 11 studies have been completed on the role of working memory limitations on storage and retrieval of information. One series demonstrated that, if subjects are highly trained and there is no interference among the items being retrieved, working memory limitations play no role in retrieval. However, if there is interference among the information being retrieved, individuals low in working memory capacity suffer in retrieval from active memory compared to high working memory individuals. Regardless of interference condition, however, working memory capacity plays no role in retrieval from inactive or secondary memory. A second series of studies demonstrated that the phonological similarity effect, one of the primary sources of evidence for the articulatory loop, is not found if the words in the lists to be recalled are chosen from an unlimited set and presented silently. This casts doubt on the generality of this code, particularly for silent reading. A third set of studies demonstrated that the negative priming effect, a principle source of evidence for cognitive inhibition, is reduced as a function of mental work load. This suggests that the ability to inhibit information irrelevant to the current task requires attentional resources.

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Considerable progress was made this year in conducting studies recommended in the original proposal. I will describe the research described in the proposal as Series 1 primarily, followed by the studies described in the proposal as Series 5 and then the work described as Series 4 in the original proposal.

Project 1.

Our earlier work (Cantor & Engle, 1993) had suggested that Hi and Lo working memory capacity subjects could differ in retrieval time from primary memory, secondary memory or both. Series 1 in the original proposal was directed at this question. A task was developed that allowed us to measure the time for the subject to retrieve an item from the active portion of memory, or primary memory, and from the inactive portion of memory, or secondary memory. Five studies were completed on this question and the results have just been accepted for publication pending revision by the Journal of Experimental Psychology: General. I will first summarize the conclusions from those studies and then describe the procedures and results that led to those conclusions. *Regardless of interference condition, Hi and Lo working memory capacity subjects do NOT differ in retrieval time from inactive or secondary memory. If there is no interference or response competition involved, Hi and Lo working memory capacity subjects do NOT differ in retrieval time from active or primary memory. Hi and Lo WM subjects DO differ in retrieval time from primary memory if the items being recognized belong to more than one set which creates interference among the items.*

Subjects in 4 experiments learned sets of items in association with a cue that was a number representing the number of items (either letters or words) in the set. In Experiment, for example, a subject might learn to recall the letters B and Q in response to the cue, 2, and the letters L, W, C and R to the cue, 4, etc. In two of the four experiments (1 & 3), there were set sizes of 2, 4, 6, & 8 and letters as set items and in two of the studies (2 & 4) there were set sizes of 2, 4, 6, 8, 10 & 12 and words were used as set items. In two of the studies

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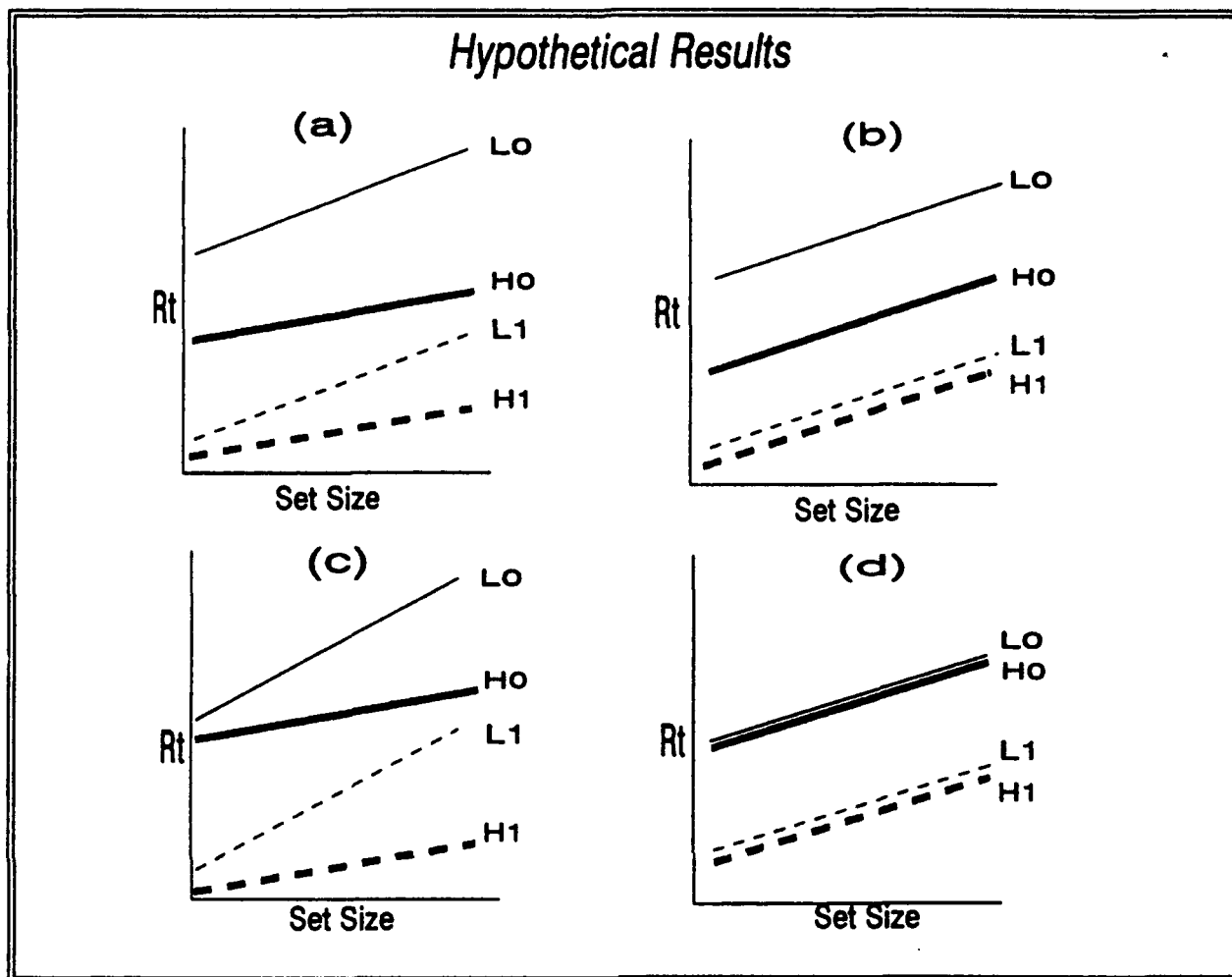
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(3 & 4) there was no overlap in set membership so that each letter or word was in one and only one set. In the other studies (1 & 2) each item was a member of 2 different sets.

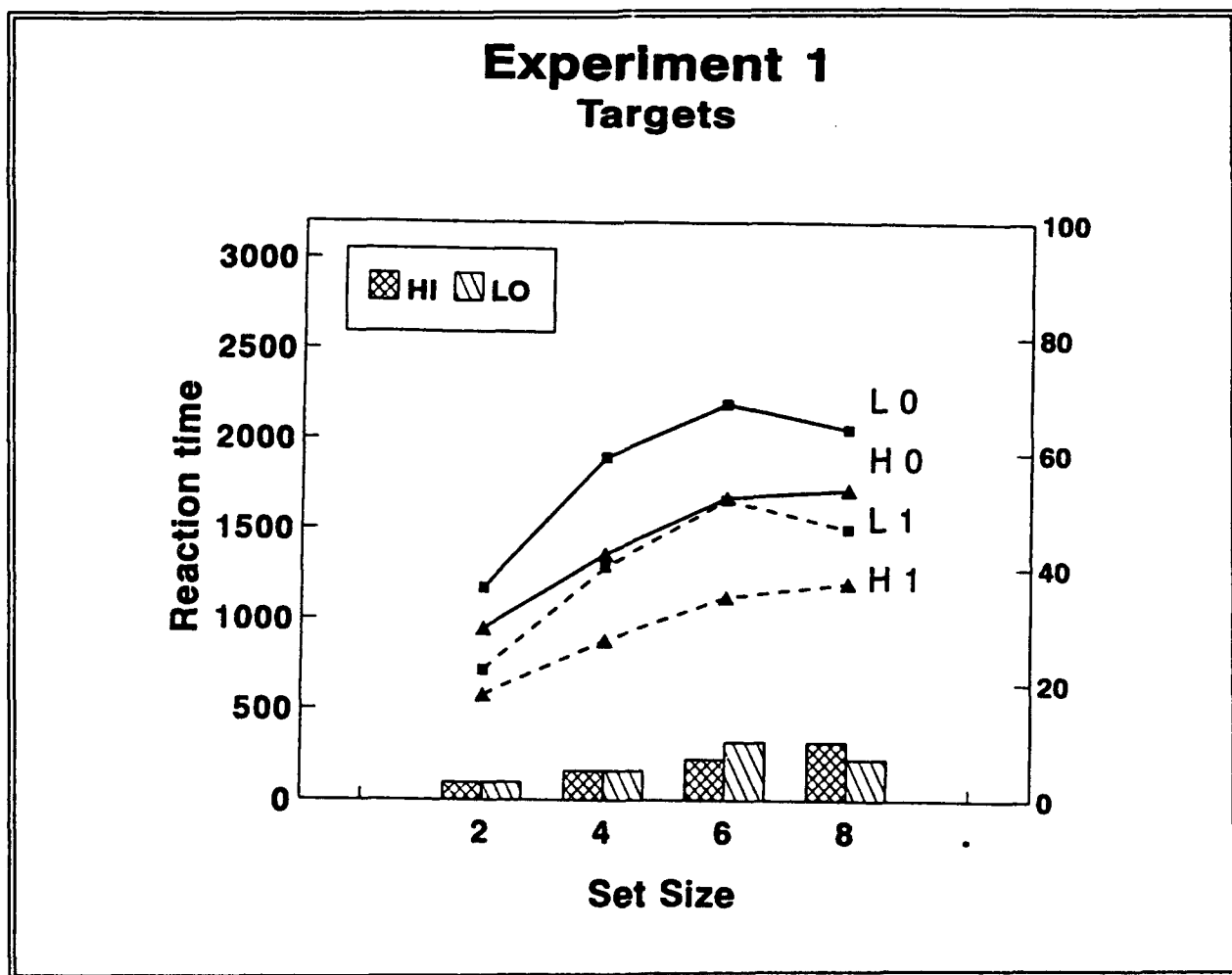
After the sets were learned to a criterion of 3 perfect recalls for each set, there was a speeded recognition task. On each trial, the subject was presented with a number representing a set (e.g., 8) and an item. The subject was to press a Yes or No key as rapidly as possible (while maintaining accuracy) as to whether the item was a member of the set being cued, in this instance, set size 8. To distinguish between active and inactive memory, on half the trials the set cue occurred alone for 1 second after which the item appeared and the reaction time was measured from the onset of the item. These trials were assumed to measure retrieval time from active or primary memory. A pilot study had shown that 1 second was more than enough time for subjects to retrieve the entire set into active memory. Thus, we felt safe in assuming that 1 second was a sufficient lead time for the subject to encode the set cue and make the set information available in active memory. We assumed that, on these trials, when the item appeared the subject would need only to search the items in the previously activated set so the measure was a valid measure of retrieval time from primary memory. On the other half the trials, the set cue and the item appeared at the same time for a 0 delay. We assumed that, on these trials, the subject must first bring the set information into active memory and then search the items in the activated set. Thus, these trials represented both the time to retrieve set information into active memory and the time to search primary or active memory. Retrieval from primary memory could be estimated by the reaction time on the 1 second delay trials. Retrieval from inactive or secondary memory could be estimated by the difference between the 1 second delay trials and the 0 second delay trials.



The figure above shows 4 possible patterns of reaction times for these experiments. Panel (c) shows the results we would expect if working memory capacity is reflected in retrieval from active memory but not retrieval from inactive memory. The difference between 0 and 1 second delay conditions (i.e., time to retrieve into active memory) would be the same for High and Low span subjects, but the slopes would differ at each delay condition. If High and Low span subjects do not differ in retrieval time from either active or inactive memory the results would look like those in panel (d).

The results of Experiments 1 & 2 most closely resemble those in Panel C. If there was overlap in set membership, as there was in Exps. 1 & 2, the difference between the set size function for delay 1 and delay 0 was not different for Hi and Lo span subjects. That is, Hi and Lo span subjects took the same amount of time to bring the set information into active

memory. They did, however, differ in the time to search the contents of the activated set since the slope of the set size function was steeper for Lo span subjects than for Hi span subjects. The results of Exp. 1 are shown in the figure below. Clearly, Hi and Lo span subjects differ in slopes suggesting that they differ in search time for primary memory. Equally clear, however, is the fact that the difference between the 0 second slope function and the 1 second slope function is no greater for Lo span than Hi span subjects. This suggests that the time to retrieve a set into active memory does not differ for Hi and Lo span subjects. That difference is not any greater for set size 8 than for set size 4 which suggests that the time to activate a set does not depend on the size of that set. The results of Exp. 2, with words as items and set sizes up to 12 showed the same pattern.



Experiments 3 & 4 used sets with no overlap in membership. In both experiments, the results look most like those in Panel D in the first figure. There was no WM difference in the retrieval time estimates for either active memory or inactive memory.

These 4 studies show that working memory capacity is not relevant to retrieval from memory unless there is a degree of interference or response competition involved in the task. We argued that, when each item was a member of 2 sets, the set cue activated the association to all items in that set and the item activated the association to both set cues. This led to a level of interference or response competition. Further, we argued that the Hi span subjects were able to inhibit the association between the item and the irrelevant set cue. However, the low span subjects, because of lower attentional resources, were not able to inhibit the link to the irrelevant set cue and thus were forced to do a full serial search of each set much like Sternberg proposed in 1966. In Experiments 3 & 4, in which there was no overlap in set membership, there was no difference between Hi and Lo span subjects in retrieval from primary or secondary memory.

Project 2.

The primary reviewer of the original proposal suggested that the set of studies I referred to as Series 5 was important and that we should try to do those early in the grant period. Five studies were conducted on this problem in the first year of the grant. The results of those studies were presented in a symposium on the articulatory loop at the Midwestern Psychological Association this year. The manuscript reporting those data is 2 weeks away from being submitted to JEP: L, M & C. Again, I will present the conclusion from those 5 experiments and then describe the procedures that led to those conclusions. *The phonological similarity effect does NOT occur when the lists are chosen from an unlimited pool of words, UNLESS, the words are spoken aloud at input. Even then, however, the effect is a quarter of the effect when the lists are chosen from a fixed set of items such that the words are used over and over again on each list.*

In each of 5 experiments we varied whether the lists items were chosen from a limited set of 7 items used over and over across lists or from a functionally unlimited set with no repetition of a word from list to list. We also varied whether the lists items were phonologically similar on each list or were dissimilar. Across experiments, we varied whether the words were read silently at input or were read aloud by the subject and whether recall was written or oral. In all experiments, if the lists were chosen from a limited set, there was a sizable phonological similarity effect regardless of input or output mode. In the unlimited condition, however, if input was silent, no phonological similarity effect was found regardless of mode of recall. If the words were articulated aloud at input, there was a small but significant effect of phonological similarity regardless of mode of recall. Even in this case, however, the phonological similarity effect was a quarter of the size of the effect in the limited set condition.

This finding is very important because it casts great doubt on the generality of the type of coding referred to as the articulatory loop. The pattern of correlations with various measures of rehearsal rate suggests that subjects in the unlimited condition with silent visual presentation do use some type of speech based code but that it is different than the articulatory loop code.

Project 3.

I proposed a series of studies to look at whether effects thought to reflect inhibition of cognitive mechanisms interact with the attentional resources available to the subject. We have completed 2 studies on this question and a report of one of the studies has been submitted to *Psychological Science*. In that study we studied the effects of mental work load on the negative priming effect. That effect occurs when subjects are required to name of two letters presented simultaneously and close together. For example, if a red and a green letter are presented at the same time, the subject would always be asked to name the red one as rapidly and accurately as possible. So, if a red A and a green B were presented on trial n, the subject would be required to name the A. Tipper and Cranston (1985) argued that, in order to attend

to the A, the subject must inhibit the B. If that is so and, on trial $n+1$, the subject sees a red B, it should take more time to name the B on that trial because it had been inhibited on the previous trial. That is exactly what is found and this effect is called the negative priming effect.

We reasoned that inhibition would require attentional resources and, if so, requiring the subject to do a secondary task that was attention demanding while they did the naming task might reduce the magnitude of the negative priming effect. We had subjects naming red letters and ignoring the green letters. Interspersed between the naming trials were words that the subject was read silently and, at some later time, they would see a question mark which signaled the recall of the words in the correct order. On the first letter naming trial after a recall, we reasoned that the subject was operating under a 0 load, when the letter was named after the first word was presented, the subjects was operating under a load of 1 and so on up to a load of 4 words. The results showed that, at 0 load, there was a sizable negative interference, i.e., the letter was named more slowly if it had been rejected on the previous trial. As load increased, however, the negative priming effect was reduced and actually became positive by load 3.

Project 4.

We have also conducted a major study at Armstrong Labs following up the results of Project 1. That study tested 430 subjects on the tasks we developed in Project 1 and we plan to compare the results of those subjects, using the CAM4 battery developed at Armstrong, with the results of the studies conducted here at USC. That study was designed to answer some specific questions about the nature of the interference that occurs when items are members of 2 different sets. That study was just recently completed and the results have not been analyzed to the point at which I can talk about them.

Scientific Articles based on the research:

1. Conway, A.R.A. & Engle, R.W. Working memory and retrieval: A resource-dependent inhibition model. Journal of Experimental Psychology: General, (accepted pending revision).
2. Engle, R.W., Conway, A.R.A., Tuholski, S.W., & Shisler, R.J. A resource account of inhibition. Psychological Science, (submitted).
3. LaPointe, L., McCorquodale, M., Smith, N.J., & Engle, R.W. The phonological similarity effect in limited and unlimited pool conditions. Journal of Experimental Psychology: Learning, Memory and Cognition, (submitted within 2 weeks).

Scientific Presentations at Conferences and AFOSR Labs:

1. Talk given to Armstrong Labs, August, 1993.
2. Poster based on Series 1 studies at Psychonomics Society Meeting, November, 1993.
3. Talk given at North Carolina Cognition Group, February, 1994.
4. Talk given at Midwestern Psychological Association, May, 1994.
5. Talk to be given at International Conference on Working Memory, Cambridge, England, July, 1994.